

Assessing the Impact of Anticipated Hydropower Changes and a Range of Ocean
Conditions on the Magnitude of Survival Improvements Needed to Meet TRT
Viability Goals

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INTRODUCTION

Seven Evolutionarily Significant Units (ESUs) of salmon and steelhead are listed as endangered or threatened under the Endangered Species Act in the Interior Columbia Basin. Two current, large-scale decision-making processes in the region will affect the future status of these ESUs. First, local, state and federal agencies are developing recovery plans for these ESUs that seek to identify strategies to improve population status and ultimately achieve recovery goals. Second, the ongoing process of developing a Biological Opinion for the Federal Columbia River Power System (currently in remand) will establish FCRPS operations having the potential to affect salmonid survival.

Fundamental to both processes will be an understanding of the current status of the populations and ESUs in the interior basin, and a sense of the survival improvements that would be required to meet recovery goals. In this report, we present the results from a life-cycle modeling effort designed to contribute to an assessment of the difference between current population abundance and productivity, and abundance and productivity targets established by the Interior Columbia Technical Recovery Team (IC-TRT).

Specifically, we estimate the magnitude of survival change required to reach those goals in the entire life cycle under current conditions in the hydropower corridor, as well as after the survival rates anticipated as the result of actions in the hydropower corridor have been imposed (2004 FCRPS BiOp). Given the ongoing negotiations about the operations of the federal hydropower system, there is strong motivation for exploring the impact of alternative hydropower scenarios on salmonid population status. Understanding the relative role that changes to direct mortality – that is, mortality within the migration corridor – can play in achieving recovery or viability goals is a critical component of crafting a robust recovery strategy.

We also evaluate the magnitude of the survival changes needed to meet TRT viability criteria under a range of ocean conditions. Recent oceanographic information (Francis and Hare 1994, Mantua et al. 1997) and life-cycle modeling (Zabel et al. 2006) have provided more information supporting the large effect of ocean conditions during the salt-water residence, and particularly the early salt-water residence of these fishes on overall

survival. Because future ocean conditions are highly uncertain, we modeled a range of ocean conditions to inform the ongoing decision-making processes.

This work therefore serves three purposes. First, it allows us to explore the relative impact of several factors on population status, and the relative magnitude of survival change that would be required to meet targets under various scenarios. We explore variation in the hydropower system and in ocean conditions. We also evaluate the magnitude of survival change required in density-dependent and density-independent situations. Second, these estimated survival changes can be used in conjunction with current observed population status metrics to estimate population-specific needed survival changes under various conditions. Finally, this work gives us the ability to assess the biological feasibility of a strategy that includes improvements both in and outside the hydropower corridor by comparing the freshwater survival rates that, coupled with survival improvements in the FCRPS, would be required to meet viability goals within the range of freshwater survival rates empirically observed for each species. Required survival rates falling within that range would suggest that meeting viability goals with actions affecting early survival is a reasonable strategy; required survival rates falling well outside that range suggest that the strategy is not plausible. [Analyses relating to this final purpose are not presented in this draft.]

It is important to remember that this is a modeling exercise designed to estimate the likely magnitude of needed changes and the likely range of response to natural variation. These kinds of estimates are critical components of planning. However, because of the uncertainty associated with future conditions, the survival changes described here should be used to guide planning efforts, rather than as targets themselves.

Key questions addressed

We evaluated scenarios including alternative hydropower system survivals and alternative early ocean survival. We asked the following questions:

- 1) *What is the effect on population status of increasing survival through the FCRPS hydropower system to levels anticipated under the 2004 Biological Opinion?*
This analysis allows us to evaluate how much of any difference between current conditions and IC-TRT viability goals can be mitigated with hydropower actions. In other words, it allows us to identify the magnitude of the gap between the viability goals and the estimated population status after these changes have been enacted.
- 2) *How does that effect change under a biologically plausible range of hydrosystem survivals?* We also evaluate an optimistic and a pessimistic scenario for the estimated survival through the hydropower system under the 2004 Biological Opinion in order to identify a range of plausible gaps between population status and IC-TRT viability goals after the imposition of hydropower improvements.
- 3) *What is the effect on population status of alternative early-ocean survival regime?*
This analysis provides additional insight into the range of plausible gaps between

population status and IC-TRT viability goals, by simulating both relatively good and relatively poor conditions for early-ocean survival.

METHODS

Populations evaluated and general model structure

We were able to construct stochastic, density-dependent matrix models for four chinook populations in the Interior Columbia (Table 1), by modifying the general structure of an ESU-level model developed by Zabel et al. (2006) for Snake River spring/summer chinook.

The stochastic life-cycle model is expressed as:

$$\mathbf{n}(t + 1) = \mathbf{A}(t) \cdot \mathbf{n}(t)$$

where the vector $\mathbf{n}(t)$ represents the number of individuals at the end of time step t by age (referenced to date of fertilization), and $\mathbf{A}(t)$ is a 5×5 population projection matrix (Caswell 2001) that varies at each time step. Based on the life history of Snake River spring and summer Chinook salmon, the matrix $\mathbf{A}(t)$ takes on the form:

$$\mathbf{A}(t) = \begin{matrix} & \begin{matrix} 0 & 0 & 0 & b_4 \cdot s_u \cdot F_4(t) & s_u \cdot F_5(t) \end{matrix} \\ \begin{matrix} s_2 \\ 0 \\ 0 \\ 0 \\ 0 \end{matrix} & \begin{matrix} 0 & 0 & 0 & 0 & 0 \\ s_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & (1-b_3) \cdot s_o & 0 & 0 \\ 0 & 0 & 0 & (1-b_4) \cdot s_o & 0 \end{matrix} \end{matrix}$$

Each element of the matrix, a_{ij} , represents the transition of i -year-olds (columns) to j -year-olds (rows) during a yearly time step. In the simplest case this is just a survival rate, such as s_2 , which is the survival of 1-year-old fish through to the second year. The b_3 and b_4 terms are the propensity for adults to breed as 3- and 4-year-olds, respectively. For example, a proportion b_4 of the 4-year-olds spawn and then die, whereas $(1 - b_4)$ of the individuals remain in the ocean, following (Ratner et al. 1997). The F_n terms describe the fertility at age n . The derivation of all these terms is described below. Stochasticity is applied in the s_3 and F_n terms; density-dependence is applied in the fertility terms.

Primary data underlying our modeling includes total spawner counts or estimates of total spawner numbers expanded from redd counts for each population in the Snake River, or from adult counts in the Chiwawa River expanded to represent the entire Wenatchee River. [We plan to modify this analysis to incorporate spawner data for the entire Wenatchee population.] These adult counts, coupled with annual age structure, provide the basis for annual estimates of productivity, or spawner-to-spawner ratios. Using smolt-to-adult return rates, we partitioned these life cycle survivals into two major

components: spawner-to-smolt survival, and smolt-to-adult survival. Within each of these major components, we further partitioned the survival as available data allowed.

Components of spawner-to-smolt survival

We estimated annual spawner-to-smolt survival by factoring previously calculated smolt-to-adult (SAR) survival rates (Petrosky et al. 2001, Williams et al. 2005; T. Cooney, unpublished data) out of the annual spawner-to-spawner ratios used in the Interior Columbia current status assessments. We assumed a common SAR for the ESU, based on dam counts. The remaining value, after factoring out the SAR, is the spawner-to-smolt survival.

The period covered by spawner-to-smolt survival -- between adult entry to freshwater and smolt departure -- is 2 years. Because the life-cycle model is based on yearly time steps, we partitioned the adult-to-smolt life stage into near-yearly increments. Density dependence and stochasticity were included in the fertility term, which is the number of 1-year-olds (parr) produced per spawner. The remaining freshwater survival was assumed to be density independent and deterministic. This preserved the overall relationship (and associated variability) between smolts and spawners. In the Upper Columbia populations, the density-independent phase included only the outmigration stage (from Tumwater Dam to Rock Island – see below).

Parr-to-smolt survival rates were derived from empirical data. For the Snake River spring/summer chinook populations, we used a mean (across several years) population-specific parr-smolt survival rate (Levin et al. 2002) that encompassed the time and distance from mid-summer in the natal basin to Lower Granite Dam. For the Wenatchee River population, we used local parr and smolt data that encompassed the time and distance from outmigration from the Chiwawa River to Rock Island Dam. Thus, the “parr-to-smolt” stage shows fairly different mortality between the two ESUs. However, the model structure remains the same. This parr-to-smolt value was factored out of the overall adult-to-smolt survival rate to produce a parr per spawner estimate (fertility term).

To generate the density-dependent, stochastic function describing fecundity, we adjusted for differential fecundity of differently-aged fish. We did not treat 3-year-olds as spawners because they were almost exclusively males. Because older fish are more fecund, we converted adult counts to “effective” spawners at time t (spawners[t]) by multiplying the number of 5-year-old fish by 1.26 to account for their approximate 26% increase in fecundity compared with 4-year-olds (Kareiva et al. 2000).

We then estimated yearly production of parr. We began with estimates of adult recruits for each population to the spawning grounds. We then divided recruits by subbasin survival (set to 0.9 as in (Marmorek et al. 1998, Kareiva et al. 2000) to determine adult recruits to the uppermost dam. For the Snake River ESU populations, we assumed that SARs derived from dam counts of the entire ESU applied to each separate population. This is reasonable because all the populations mix at the uppermost dam where fish are enumerated. Thus, we divided recruits to the uppermost dam by SAR to yield an estimate of smolts. We then divided this estimate of smolts by population-specific parr-

to-smolt survival (mean of yearly estimates from PIT-tag data) to estimate the number of parr produced by a particular brood year. Thus,

$$parr_{t+1} = R_t / (0.9 \cdot SAR_{t+2} \cdot S_{p-s}),$$

where R_t is recruits from brood year t measured at the spawning ground, and S_{p-s} is population-specific parr to smolt survival.

We used a similar procedure to generate estimates for the Wenatchee River spring chinook population. SAR estimates were based on the Chiwawa parr/outmigrant smolt monitoring programs (e.g., (Hillman and Miller 2002), WDFW unpublished data), expanded in time using an index of annual smolt-to-adult survival for Leavenworth Hatchery releases. Spawner estimates were based on expanded redd counts.

Following Zabel et al. (2006), we applied a Beverton-Holt relationship to estimate the number of one-year-olds (parr) at time $t + 1$ ($n_1[t+1]$) per spawner as a function of spawners:

$$\frac{n_1(t+1)}{spawner(t)} = \frac{a}{1 + b \cdot spawner(t)}$$

where the parameter a is juveniles per spawner at the origin, b is the density-dependent parameter, and a/b is the carrying capacity of the system. We conducted a standard log-normal transformation on the residuals. Further, we used a Box-Cox transform to account for variance decreasing with increasing spawners (see Zabel et al. 2006 for details). Plots of these fits are provided in Figure 1 and parameter estimates are provided in Table 2.

Components of Smolt-to-Adult Survival

We divided smolt-to-adult survival into five components: system survival through the hydrosystem (consisting of survival of in-river migrants, and, where relevant, proportion of fish transported, survival of transported fish, and differential delayed mortality associated with transportation or ‘D’); estuarine and early ocean survival; adult ocean survival; upstream migration survival rate; and in-river harvest.

Several of these components we derived from the literature: We assumed adult ocean survival of $s_o = 0.8$ (Ricker 1976) and applied it according to the number of years spent in the ocean. This assumption is consistent with previous cohort based chinook modeling studies (Petrosky et al. 2001, PSC 2003, 2004, 2005). Upstream migration survival in the Columbia, or the Columbia and Snake, was set at $s_u = 0.806$, based on recent PIT-ta survival estimates. In-river harvest rates were derived from (Petrosky et al. 2001, Williams et al. 2005) and TAC estimates, and hydrosystem survival components were taken from Williams et al. (2001), and Williams et al. (2005). See Table 2 for details.

With these values set, we were able to back-calculate third-year survival ($s_3(t)$) estimates from SAR data while taking into account year-to-year variability in hydrosystem survival, harvest, and age composition of returning adults. (Yearly hydrosystem survival values used in these calculations are presented in Appendix B.) Specifically, we based this value on smolt counts at year t and age-specific adult counts at years $t+1$, $t+2$, and $t+3$ at the uppermost dam. We note that:

$$s_3(t) = n_3(t+1)/n_2(t),$$

where $n_i(t)$ is the number of individuals of age i at time t .

The $n_2(t)$ term is derived from the number of smolts as follows:

$$n_2(t) = s_d(t) \cdot \text{smolts}(t), \text{ and} \\ s_d(t) = p_T(t) \cdot s_T + (1 - p_T(t)) \cdot s_I(t)$$

where $s_d(t)$ is survival of downstream migrants through the hydrosystem, $p_T(t)$ is the portion of fish arriving at the uppermost dam that were transported (Marmorek et al. 1998; Williams et al. 2005), s_T is the survival of transported fish, and $s_I(t)$ is the survival of in-river migrants (Williams et al. 2001, Williams et al. 2005). Downstream survival estimates were lacking for 1981–1992, so we interpolated between the earlier period and the later period. The s_T parameter includes a mean “delayed differential mortality” of transported fish (from Williams et al. 2005), accounting for the fact that transported fish return at lower rates than fish that migrated volitionally. Although this delayed mortality is most likely expressed during the early ocean life stage, we applied it to the downstream migration stage because it simplifies calculation of the early ocean survival term and is mathematically equivalent. However, if ‘D’ is variable between years, there is the potential that variability has been mis-apportioned. We are currently working on sensitivity analyses to evaluate the potential impact of variable delayed transportation mortality.

We calculated $n_3(t+1)$ from the number of adults returning as 3-year-olds in $t+1$ (designated $n_{A3}[t+1]$), the number of 4-year-olds returning in $t+2$ (designated $n_{A4}[t+2]$), and the number of 5-year-olds returning in $t+3$ (designated $n_{A5}[t+3]$). These counts were then adjusted to account for mortality occurring during upstream migration, harvest rate in the river, and ocean survival. In this manner, we estimated $n_3(t+1)$ as:

$$n_3(t+1) = 1/su \cdot \{ (n_{A3}(t+1))/(1-hr(t+1)) + (n_{A4}(t+2))/(so \cdot [1-hr(t+2)]) \\ + (n_{A5}(t+3))/(so^2 \cdot [1-hr(t+3)]) \}$$

We used these estimates of n_3 and n_2 to estimate annual s_3 values. We then associated the third-year survival values with environmental indices of climate to establish a relationship that would allow us to simulate third-year survival.

Simulating third-year survival

We explored a number of potential climate indicators for predicting annual third year survival: monthly PDO (Mantua et al. 1997) alone; and monthly PDO combined with upwelling, sea surface temperature and water travel time. In addition, we tested the effect of using subsets of years as a response variable in order to evaluate the possibility that the relationship between climate and early ocean survival was different in different time periods. We chose between these models using a combination of AIC/BIC scores and evaluating the proportion of variation that each model explained. Finally, we evaluated the performance of a simple autocorrelation function against that of a climatic predictor.

Single Factor Model – PDO alone

We chose regressions using all years, except migration years 1986-1991 (for which data were not available), and the monthly PDO indices of April, May and June as the best predictors of third year survival (see Appendix A for more details on other options). We used a logistic transformation of $s_3(t)$, which resulted in normally distributed residuals and ensured that the resulting (back-transformed) survival estimates were bounded on the range 0.0 to 1.0. Thus, our multiple regression between $s_3(t)$ and monthly PDO indices was:

$$\ln[s_3(t)/(1 - s_3(t))] = \beta_0 + \beta_{\text{APR}} \cdot \text{PDO}_{\text{APR}}(t) + \beta_{\text{MAY}} \cdot \text{PDO}_{\text{MAY}}(t) + \beta_{\text{JUN}} \cdot \text{PDO}_{\text{JUN}}(t) + \varepsilon t,$$

where t is the year of ocean entry, β_{month} represents regression coefficients, $\text{PDO}_{\text{month}}(t)$ is the PDO index in the given month (e.g., April = APR) in year t , and εt is the error term distributed as $N(0, \sigma^2_3)$. To apply these results predictively to the life-cycle model, we used the monthly PDO indices for 1900–2002. We generated variability about the predicted survival based on Eq. 20.34 (Zar 1984), which is the standard error about predicted response values from a multiple regression that takes into account covariance among the independent variables. Fits between predicted and observed third-year survival rates are shown in Figure 2.

Multiple Factor Model

The best fit multiple factor model included “water travel time,” (WTT) or number of days that in-river fish take to migrate through the hydropower system, April upwelling index and the May PDO index. Incorporating this model into our analyses responds to concerns that monthly PDO indices co-vary, and are not independent predictors of s_3 . Using water travel time will also allow us to link this life-cycle model explicitly and easily to ongoing passage modeling work. Some preliminary results are shown in Appendix A.

Currently, any latent mortality attributable to the hydropower system is implicitly incorporated in our s_3 value. We are also developing methods to include this potential factor explicitly, and thus be able to evaluate the sensitivity of the model and its responses to a range of potential latent mortality values.

Modeled Scenarios -- Anticipated survival rates in the hydropower corridor

We included four parameters in the hydropower corridor survival rate: in-river survival; proportion transported; survival of transported fish; and differential delayed mortality of transported fish (D). We modeled several deterministic scenarios of hydro-related mortality and survival to bound the range of likely survival rates through the hydropower corridor (Table 3).

- First, we modeled the average hydropower parameters observed through the time period on which we based our current status assessments (IC-TRT, in development). This scenario allowed us to calibrate the proportional change in life-cycle survival rates under other scenarios to this “current baseline” survival.
- Second, we used the mean survival rates estimated with PIT-tag technology for the most recent 5 years (Williams et al. 2005). For those ESUs that are subject to transportation of juveniles, we also used the mean proportion transported and the differential delayed mortality rate of those fish (D) as estimated from PIT-tag returns. Current survival rates for hydropower projects in the Upper Columbia (operated by the Mid-Columbia Public Utility Districts) were obtained from (Skalski et al. 2005) and (Grant PUD 2003). These estimates formed the basis of our “current hydro survival” scenario for hydropower survival, and allowed us to evaluate the likely proportional change that may be obtained as a result of continuing current hydropower operations for a longer period of time (and thus, to compare these with the “current baseline” survival rates).
- Next, to evaluate the likely effects of additional anticipated improvements in the hydrosystem, we applied the mean proportional change to each of these parameters predicted by SIMPAS as a result of the hydropower actions included in the 2004 FCRPS Biological Opinion (NMFS 2004). These adjusted parameters served as our average or “mean BiOp” scenario. However, hydro survivals are relatively variable. Therefore, we bracketed the likely range of hydro survivals by adding or subtracting one standard error of the current estimates (Williams et al. 2005) from the mean hydro scenario. This produced an “optimistic” and a “pessimistic” hydropower scenario.

Parameters relevant for survival through the hydropower system are presented in Table 3.

Modeled scenarios -- Climatic and ocean conditions

Because Pacific salmon population dynamics appear to be associated with ocean conditions (Mantua et al. 1997), we varied the PDO time series that we used in our model runs to simulate three different scenarios, chosen to bracket a range of potential futures:

- First, we applied the time series that also applied to our current status assessments (1980-2001). This, as with the “current baseline” hydropower scenario, allowed us to calibrate the proportional change in life-cycle survival rates between alternate scenarios.

- Next, we simulated conditions equivalent to those seen over the entire historical time period. We applied PDO conditions seen over the past 100 years. This allowed us to assess the potential change in population status attributable to an ocean regime more like that seen over the past 100 years.
- The final scenario simulated “poor” ocean conditions. For these simulations, we used only ocean conditions or smolt-to-adult survival rates seen during the period from 1975-1998, a period of below average early ocean survival and higher than average PDO values.

These two additional scenarios serve as endpoints for a plausible range of likely futures.

Scenarios Evaluated and Response Variables

We evaluated all possible combinations of the hydropower and ocean condition scenarios (Table 4), beginning each simulation with the population-specific geometric mean number of spawners seen in the last five years, and using the mean age structure of the population to back-fill the other age classes. We ran the model 100,000 times per scenario to derive means and standard deviations, and accurate probabilities where appropriate.

We used several response variables to assess population status in each of these model runs. The first three of these directly measure population performance:

- Median spawner number. We chose median spawner number as a reasonable indicator of the population equilibrium value.
- Intrinsic productivity. We evaluated intrinsic productivity as the geometric mean of productivities observed at spawner levels below 75% of the IC-TRT defined minimum threshold for each population.
- Probability of quasi-extinction. We calculated the probability that the population would fall below 50 spawners for each of four consecutive years. This metric is reported merely as an indicator of overall population status, not as a viability goal or target.

The remaining four metrics measure the change that would be required at particular life stages or population characteristics to meet IC-TRT viability goals.

- % change in Beverton-Holt “a.” This measures the needed change if that change only occurs in the density-dependent freshwater life stage.
- % change in “capacity.” This measures the change in the Beverton-Holt capacity (a/b) that would be required to meet the viability curve.
- % change in parr-smolt survival. This measures the required change in a density-independent, freshwater life stage.
- % change in in-river survival. This measure the required change in survival of in-river migrating smolts required to meet the viability curve.

For each of these “needed change” metrics, we calculated the percent change in the parameter of interest, up to 100% survival. Any change requiring greater than 100% survival was rated as “not possible” for evaluation purposes.

RESULTS

A complete tabulation of response metrics from these analyses is presented in Table 5. Here we summarize some key results.

Scenario Evaluation: Proportional Change in Life-Cycle Survival under Alternate Scenarios

Impact of survival through the hydropower system

Survival through the hydropower system (not accounting for any potential delayed mortality of in-river outmigrants) had an effect on overall life-cycle productivity. In particular, the changes from the “current baseline” scenario -- that which sought to replicate the conditions implicit in the IC-TRT’s current status assessments -- to a scenario that included only hydropower parameters observed since 1995, had a substantial impact on life-cycle survival rates (Figure 3). This difference is significant across all populations (paired t -test, $t=9.123$, $p<<0.0001$, $df=11$). The difference between the increase expected under full implementation of the 2004 FCRPS Biological Opinion was also significant in comparison with those survivals that are currently being observed (paired t -test, $t=5.309$, $p=0.0001$, $df=11$), but the overall magnitude of life-cycle improvement that is likely to be achieved with these additional improvements is relatively smaller, unless those changes also affect survival at later life stages. The relative ratio of productivity under each scenario is presented in Table 6.

Impact of early ocean survival scenarios

Early ocean survival patterns had an even more significant effect on overall population productivity (Figure 4). In comparison with our “current baseline” scenario, productivities under the historical (100-year) PDO cycle were highly significantly larger (paired t -test, $t=12.624$, $p<<0.0001$, $df=11$), and those under “poor” conditions (like those from 1977-1998), were significantly lower (paired t -test, $t=-8.492$, $p<<0.0001$, $df=11$). Early ocean survival, in the construction of this model, includes all mortality -- natural and anthropogenic -- that occurs from the base of Bonneville dam until the fish’s third birthday. The relative ratio of productivity under each scenario is presented in Table 6.

Biological Feasibility

[This write-up will be included in the next draft. Please see “Next Steps” for analyses that are currently underway or are planned.]

CONCLUSIONS

[To be refined in content and expanded into better prose in next draft.]

- Early ocean conditions can have a profound effect on the magnitude of survival change that may be required to meet IC-TRT viability criteria. If ocean conditions are like those seen over the last 100 years, relatively small changes at other life stages may be required. However, if early ocean conditions are more like those seen in the last 20-25 years for prolonged periods in the future, much greater increases in survival will be required to meet those criteria.
- Changes for fish made to the hydropower system have improved the likely status of these populations. Modeled populations with hydropower system survivals like those that have been seen in the relatively recent past (since 1995) show higher productivity than those with parameters similar to those seen since 1980.
- Additional improvements in hydropower system survival anticipated in the 2004 Biological Opinion can improve overall population productivity by small but significant amounts.
- The magnitude of change required to meet viability goals may vary, particularly if mortality in the estuary/early ocean phase is distributed differently than has been modeled here (e.g., if transportation-related delayed mortality ('D') is variable between years, or if a large portion of the mortality in that stage is constant, latent mortality attributable to the hydropower system). We are currently working on sensitivity analyses to evaluate the likely magnitude of response and needed change with these scenarios.
- Again, the difference between modeled status and IC-TRT viability goals is a modeling result. These are extremely useful for planning purposes, allowing policy-makers to weigh the relative risk of various options and the relative magnitude of needed change. The quantitative difference between a modeled scenario and viability goals should not be treated as a goal.

NEXT STEPS

The following steps are either underway or will be undertaken in the very near future:

- Alternate ocean survival predictive model. As described above, we are exploring the inclusion of alternative predictor variables to our regression model that predicts early ocean survival. Preliminary results of these analyses are shown in Appendix A. We will include this model as an alternative to our PDO predictor.
- Inclusion of latent mortality. We are exploring several options that would allow us to include latent mortality attributable to the hydropower system explicitly in this model. This will allow us to conduct sensitivity analyses examining the potential impact of various possible levels of latent mortality.

- Biological feasibility. We can conduct several analyses that will allow us to assess the biological feasibility of actions in several arenas. Specifically, we are in the process of investigating the following:
 - Estimating the egg-smolt survival that, coupled with 2004 FCRPS BiOp survival rates, would produce overall life-cycle productivities meeting IC-TRT viability criteria, and comparing those survivals to the range of egg-smolt survival rates that have been observed for stream-type chinook salmon (and ultimately steelhead; see below).
 - Modeling a scenario that imposes 100% hydrosystem (direct) survival, and comparing the resulting productivity to IC-TRT viability criteria. This is a “thought experiment” that can provide insight into the potential need for actions outside the hydropower corridor and first-year survival.
 - Incorporating a term that accounts for mortality/survival from Bonneville Dam to the mouth of the Columbia. Recent acoustic-tag information has provided some estimates of this survival that would allow us to conduct informed sensitivity analyses on the effect of this stage on overall population productivity.
- Density-dependent vs. density-independent survival. For compatibility with the ongoing Biological Opinion remand process, we have reported here the differences in overall life-cycle productivity. However, our modeling results also allow us to examine the effect of changes at density-dependent stages vs. those that are density-independent. We will provide this information in the next draft.
- Broader treatment of output metrics. In this report, we have focused on life-cycle productivity as an output metric. However, we have generated a number of additional metrics that will almost certainly provide further insights into population dynamics.
- Additional ESUs and populations. Obviously, stream-type chinook are not the only ESUs in the interior basin that are listed under the Endangered Species Act. We are in the midst of developing a matrix model for two steelhead ESUs: the Mid-Columbia and Snake River ESUs (data are not available to support such a model for Upper Columbia steelhead). Snake River Fall chinook have proved to be extremely difficult to treat in a matrix format due to lack of data; we anticipate that we will be able to provide some general information about this ESU, without requiring a full matrix model.

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Table 1. Treatment of populations belonging ESUs listed under the Endangered Species Act in the Interior Columbia basin in this and subsequent reports.

ESU	MPG	Population	Habitat condition from (McClure et al. 2004)	Treatment for this report
Snake River spring/summer chinook	Middle Fork Salmon River	Marsh Creek	Very good (minimal impacts)	Modeled
	South Fork Salmon River	South Fork Salmon mainstem	Moderate (some areas with probability of significant impacts)	Modeled
	Grande Ronde/Imnaha	Catherine Creek	Poor (substantial probability of high impacts)	Modeled
Upper Columbia spring chinook	East Cascades	Wenatchee	Moderate (some areas with probability of significant impacts)	Modeled
Snake River steelhead	Salmon River	Little Salmon River	Poor (substantial probability of high impacts)	Will be included in next draft
Upper Columbia steelhead	All	Any	Moderate (some areas with probability of significant impacts)	No matrix can be developed
Mid-Columbia steelhead	Umatilla-Walla Walla	Umatilla River	Poor (substantial probability of high impacts)	Will be included in next draft
Snake River sockeye	Stanley Lakes Basin	Any	Very good (minimal impacts)	No matrix can be developed
Snake River fall chinook	Lower Snake River mainstem	Lower Snake River mainstem	Not evaluated; substantial habitat effects related to hydrosystem operation	Substantial additional work required to develop a matrix for this ESU; some guidelines will be provided in the next report

Table 2. Parameters used in Leslie matrix models for Marsh Creek, Catherine Creek, South Fork Salmon River, and Wenatchee River populations.

	Marsh Creek	Catherine Creek	South Fork Salmon River	Wenatchee River
Beverton-Holt "a"	1216.169	1181.242	7259.903	402.1
Beverton-Holt "b"	0.00405	0.00114	0.00872	0.000258
σ^2_1	2.68×10^{-3}	1.57×10^{-6}	3.69×10^{-1}	1.02×10^{-6}
ϕ (variance term)	2.95	7.1	0.0	4.0
Parr-smolt survival ¹	0.161	0.164	0.114	0.5138
Hydrosystem survival	Dependent upon scenario run (see Table 3)	Dependent upon scenario run (see Table 3)	Dependent upon scenario run (see Table 3)	Dependent upon scenario run (see Table 3)
S3	Stochastic variable, dependent on relationship to ocean conditions	Stochastic variable, dependent on relationship to ocean conditions	Stochastic variable, dependent on relationship to ocean conditions	Stochastic variable, dependent on relationship to ocean conditions
Adult ocean survival	0.8	0.8	0.8	0.8
Propensity to breed (3 year olds)	0.0345	0.0345	0.0345	0.046
Propensity to breed (4 year olds)	0.4592	0.4592	0.4592	0.514
Fecundity factor	1.26	1.26	1.26	1.00
Harvest rate	0.07	0.07	0.07	0.09
Bonneville-to-basin survival rate	0.806	0.806	0.806	0.779
Pre-spawning survival rate	0.9	0.9	0.9	0.9
Initial abundance	75	67	695	781

¹ Note that parr-smolt survival for the Snake River spring/summer chinook populations measures survival from summer parr, overwintering to the top of Lower Granite Dam. Parr-smolt survival for the Wenatchee River population measures survival from exiting the

Table 3. Hydropower scenario survival rates.

ESU		Observed	Current Operations	se	2004 Biological Opinion			
					(proportional change)	Mean	Optimistic	Pessimistic
SRSS Chinook			mean					
	In-river	0.334	0.486	0.054	0.122	0.545	0.599	0.491
	% transported	0.600	0.800	0.047		0.800	0.847	0.754
	D	0.533	0.533	0.080		0.533	0.613	0.453
UC Chinook -- Wenatchee								
	Rock Island		0.934	0.004				
	Wanapum		0.920	0.028				
	Priest Rapids		0.951	0.017				
	MCN-BON (SRSS Chinook)	0.663	0.667	0.046	0.092	0.728	0.774	0.682
	Total RIS-MCN	0.690	0.817	0.029		0.817	0.846	0.788
	Alternate scenario -- HCP targets			0.029		0.804	0.833	0.775
MC Steelhead								
	McNary to Bonneville (SR steelhead)		0.540	0.071	0.081	0.584	0.655	0.513
	John Day to Bonneville (SR Steelhead)		0.728	0.048	0.049	0.763	0.811	0.715
SR Steelhead								
	In-river		0.346	0.060	0.102	0.381	0.441	0.321
	% transported		0.845	0.039		0.845	0.884	0.806
	D		0.582	0.166		0.582	0.748	0.416

ESU		Observed		Current Operations		2004 Biological Opinion				
				mean	se	(proportional change)	Mean		Optimistic	Pessimistic
UC Steelhead -- Wenatchee										
	Above RIS to McNary			0.537	0.109		0.537		0.646	0.428
	(wild)									
	MCN to BON			0.611	0.217	0.081	0.661		0.878	0.444
	(hatchery)									
	RIS to BON			0.328	0.279					
	PUD dam-specific estimates									
	RIS			0.956	0.011					
	WAN			0.901	0.006					
	PRD			0.940	0.042					
	Alternate RIS to BON									

Table 4. Climate and hydropower survival scenarios used in evaluating the biological feasibility of Interior Columbia salmon and steelhead populations meeting IC-TRT viability goals.

Hydro Scenario	Climatic Scenario
Current (Williams et al. 2005)	Last 100 years
	“Bad” conditions only
	Most recent 25 years
Current + anticipated mean hydro improvements (FCRPS BiOp, 2004)	Last 100 years
	“Bad” conditions only
	Most recent 25 years
Current + pessimistic anticipated hydro improvements (FCRPS BiOp, 2004 – 1 standard error)	Last 100 years
	“Bad” conditions only
	Most recent 25 years
Current + optimistic anticipated hydro improvements (FCRPS BiOp, 2004 + 1 standard error)	Last 100 years
	“Bad” conditions only
	Most recent 25 years

Table 5. Median spawner number, growth rate, probability of quasi-extinction, and increases in several parameters to meet IC-TRT viability criteria under modeled conditions. “n.p.” indicates that the survival improvement needed was greater than 200%.

Population	Climate Scenario	Hydro Scenario	Population Parameters				
			Median Spawners	Std. Dev.	Growth Rate	Std. Dev.	Prob (QET)
Catherine Cr.	Poor	BiOp	809.6	186.7	1.171	0.191	0.863
Catherine Cr.	Poor	Current ops.	778.5	183.3	1.150	0.184	0.872
Catherine Cr.	Poor	Observed	600.2	160.7	1.026	0.148	0.934
Catherine Cr.	Historical	BiOp	1961.0	319.1	1.988	0.579	0.582
Catherine Cr.	Historical	Current ops.	1900.9	313.9	1.943	0.551	0.592
Catherine Cr.	Historical	Observed	1558.3	277.1	1.671	0.400	0.657
Catherine Cr.	Observed	BiOp	959.2	208.2	1.365	0.264	0.821
Catherine Cr.	Observed	Current ops.	924.8	203.5	1.334	0.252	0.832
Catherine Cr.	Observed	Observed	723.2	178.1	1.167	0.197	0.900
Marsh Cr.	Poor	BiOp	826.5	99.2	1.262	0.152	0.148
Marsh Cr.	Poor	Current ops.	807.8	97.3	1.245	0.147	0.165
Marsh Cr.	Poor	Observed	694.2	87.1	1.144	0.121	0.322
Marsh Cr.	Historical	BiOp	1570.0	198.6	1.907	0.389	0.036
Marsh Cr.	Historical	Current ops.	1531.7	194.3	1.872	0.374	0.040
Marsh Cr.	Historical	Observed	1317.0	167.8	1.685	0.295	0.084
Marsh Cr.	Observed	BiOp	941.4	120.3	1.478	0.220	0.160
Marsh Cr.	Observed	Current ops.	918.5	116.8	1.449	0.211	0.177
Marsh Cr.	Observed	Observed	791.1	98.8	1.300	0.168	0.330
South Fork	Poor	BiOp	237.0	51.0	0.976	0.101	1.000
South Fork	Poor	Current ops.	227.5	50.1	0.962	0.097	1.000
South Fork	Poor	Observed	175.0	42.6	0.885	0.081	1.000
South Fork	Historical	BiOp	578.5	94.5	1.473	0.251	0.926
South Fork	Historical	Current ops.	560.9	92.5	1.448	0.240	0.937
South Fork	Historical	Observed	459.4	80.3	1.296	0.188	0.983
South Fork	Observed	BiOp	283.1	58.3	1.079	0.130	1.000
South Fork	Observed	Current ops.	272.4	56.9	1.061	0.125	1.000
South Fork	Observed	Observed	212.5	48.7	0.961	0.101	1.000
Wenatchee R.	Poor	BiOp	742.6	350.2	0.742	0.092	0.637
Wenatchee R.	Poor	Current ops.	547.0	294.0	0.690	0.081	0.797
Wenatchee R.	Poor	Observed	261.0	196.1	0.598	0.067	0.968
Wenatchee R.	Historical	BiOp	3076.4	923.1	1.176	0.279	0.117

			Population Parameters				
Population	Climate Scenario	Hydro Scenario	Median Spawners	Std. Dev.	Growth Rate	Std. Dev.	Prob (QET)
Wenatchee R.	Historical	Current ops.	2567.3	818.9	1.078	0.234	0.177
Wenatchee R.	Historical	Observed	1725.7	641.2	0.910	0.168	0.383
Wenatchee R.	Observed	BiOp	1110.2	457.0	0.837	0.129	0.476
Wenatchee R.	Observed	Current ops.	855.0	390.1	0.772	0.110	0.639
Wenatchee R.	Observed	Observed	463.6	274.9	0.661	0.083	0.902

Table 6. Ratio of life-cycle productivity under alternative modeled scenarios.

ESU	Scenario	Mean Ratio to "Current observed"
Snake River spring/summer chinook	Hydro -- observed	1.00
	Hydro -- current operations	1.12
	Hydro -- 2004 BiOp	1.14
	Early ocean -- observed	0.85
	Early ocean -- "poor"	1.00
	Early ocean -- "historical"	1.39
Upper Columbia spring chinook	Hydro -- observed	1.00
	Hydro -- current operations	1.17
	Hydro -- 2004 BiOp	1.27
	Early ocean -- observed	1.00
	Early ocean -- "poor"	0.64
	Early ocean -- "historical"	1.39

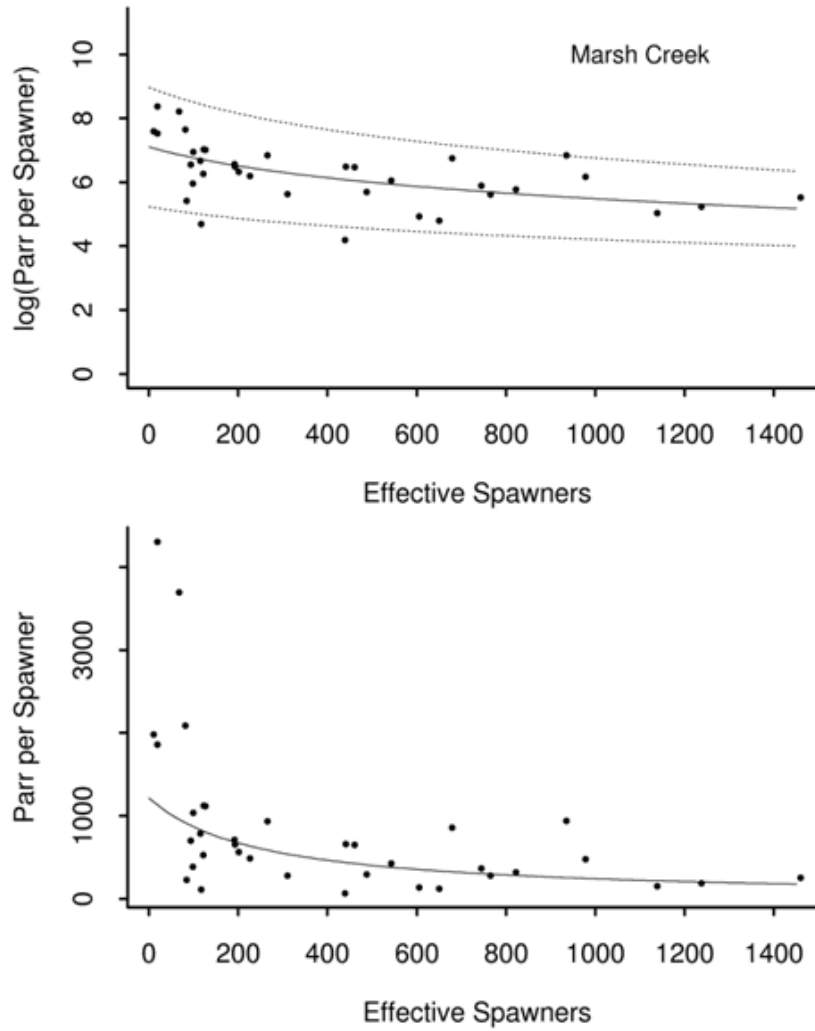


Figure 1a. Spawner number and parr per spawner, plotted with Beverton-Holt fits for the Marsh Creek population.

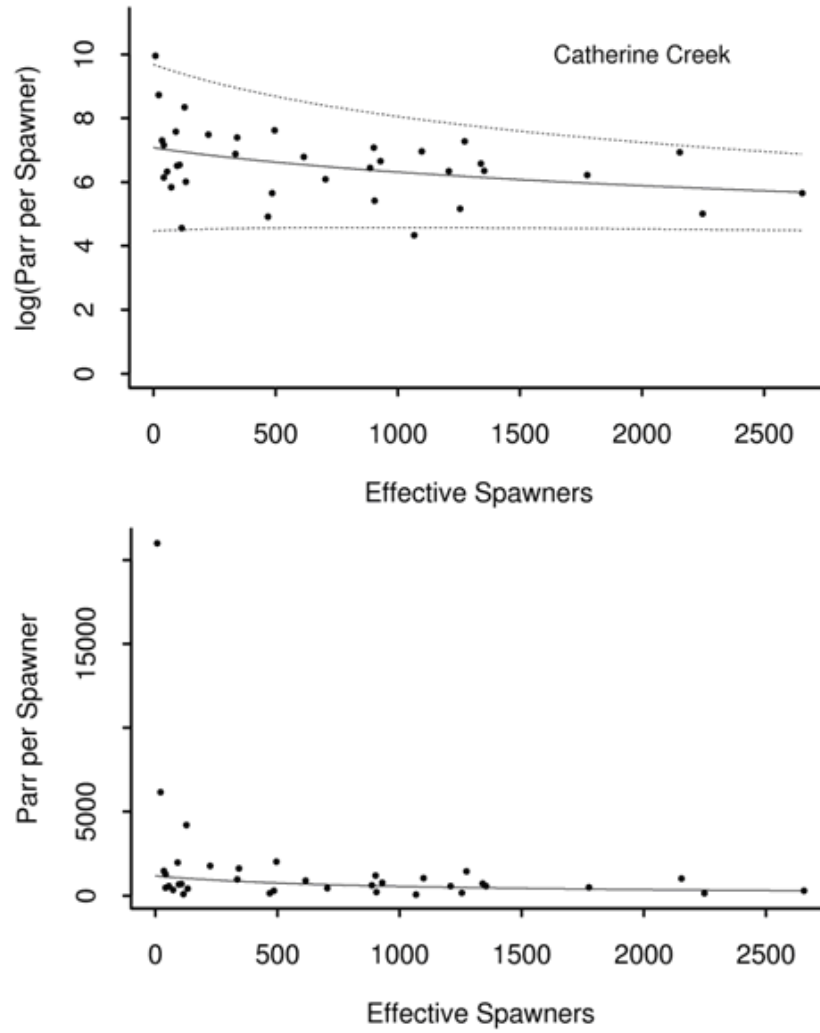


Figure 1b. Spawner number and parr per spawner, plotted with Beverton-Holt fits for the Catherine Creek population.

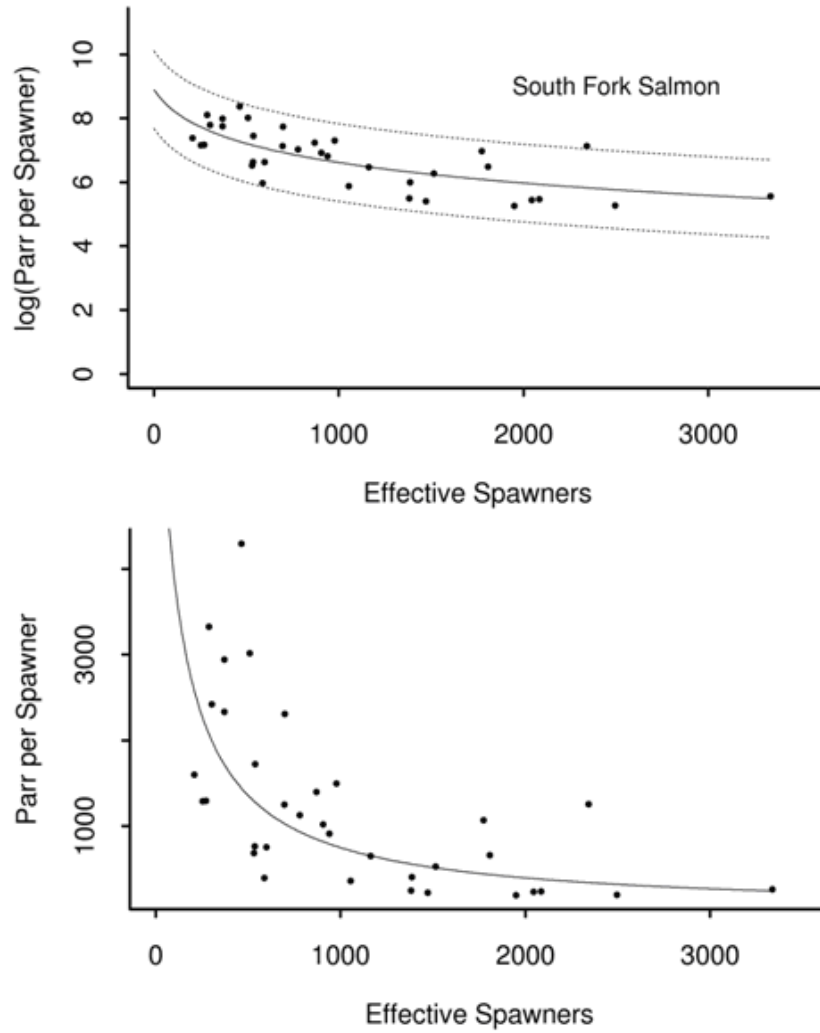


Figure 1c. Spawner number and parr per spawner, plotted with Beverton-Holt fits for the South Fork Salmon River population.

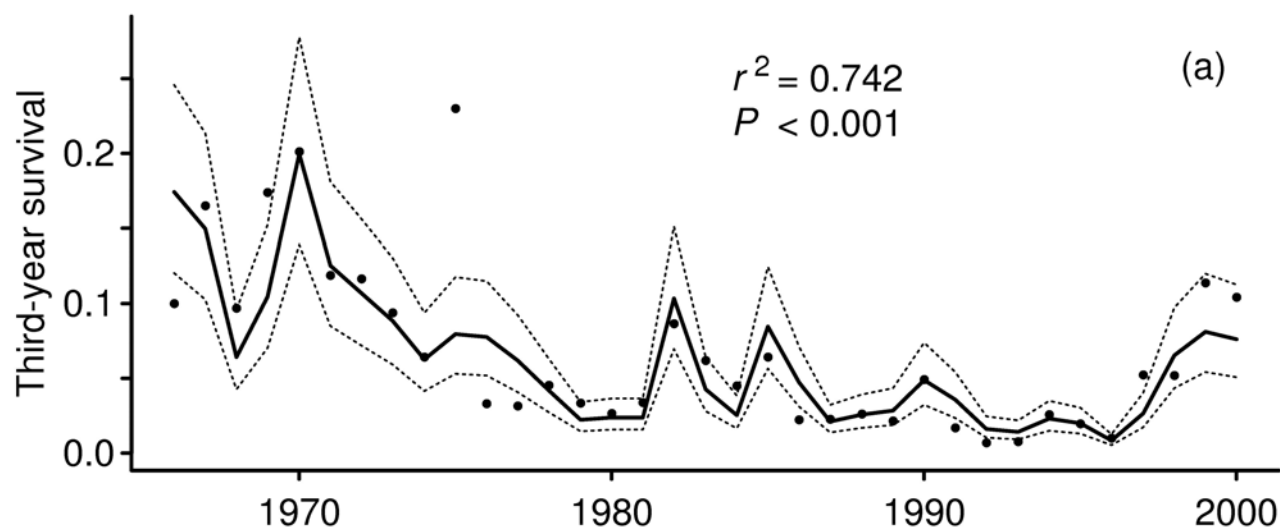


Figure 2. Actual third-year survival and predicted third-year survival rates, based on relationship with April, May and June PDO indices. Dotted lines indicate the confidence interval around the prediction.

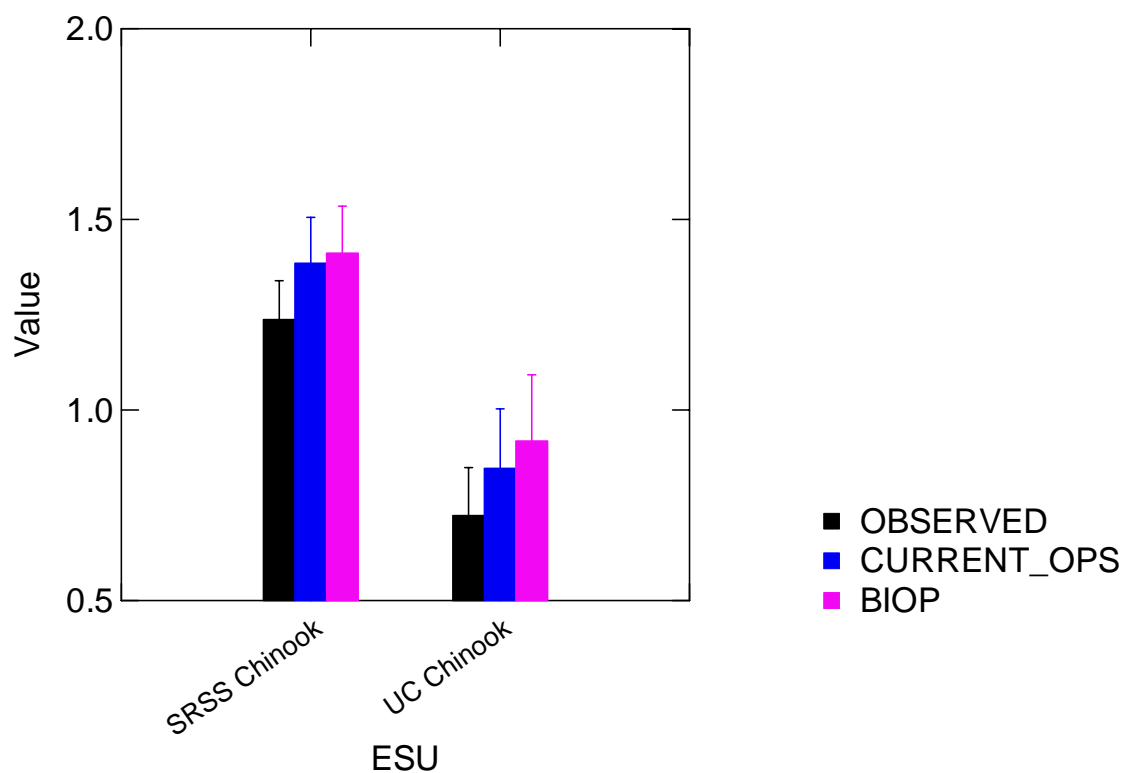


Figure 3. Mean life-cycle productivity under alternate hydropower scenarios. Observed is parameters replicating conditions present from 1980-2001, Current Ops is using survival parameters currently observed, and BiOp is the anticipated improvement with the full implementation of the 2004 FCRPS BiOp.

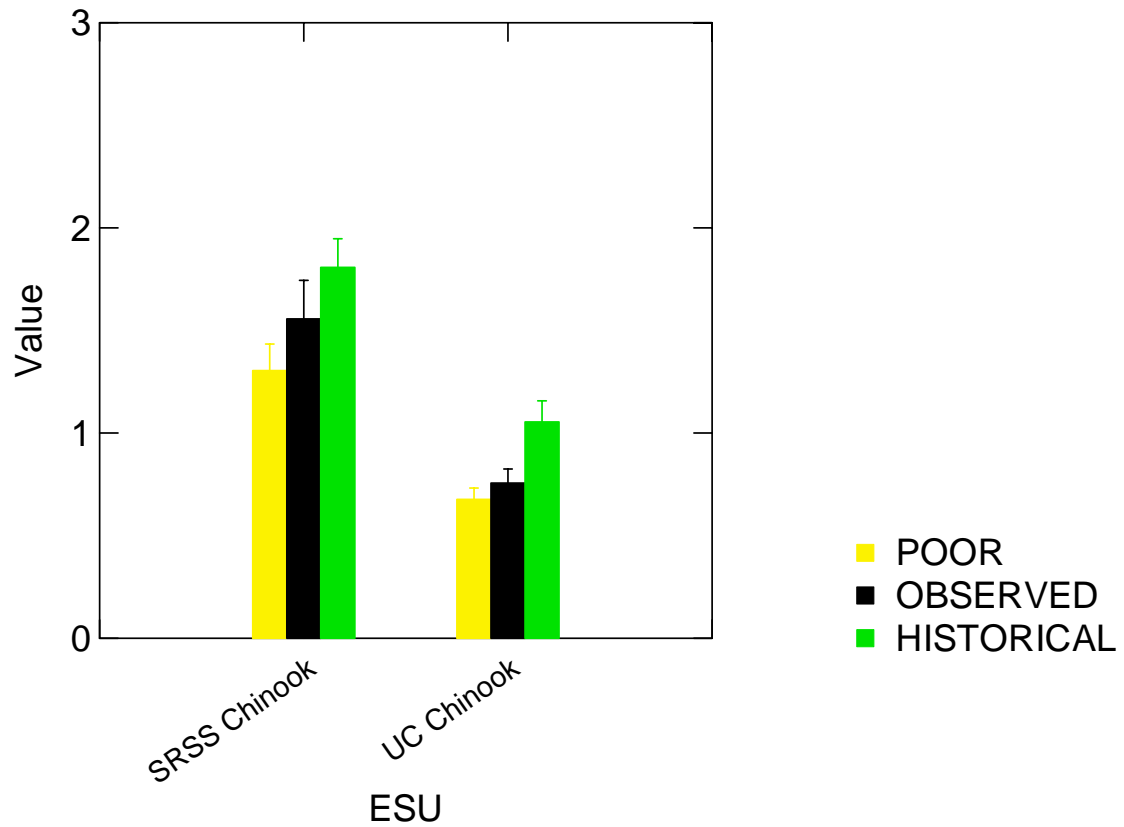


Figure 4 Mean life-cycle productivity under alternate early ocean survival scenarios. “Poor” imposes PDO values equivalent to those observed from 1977-1998; “Observed” imposes PDO values equivalent to those observed from 1980-2001, to match our current status assessments; and “Historical” imposes the full range of PDO values seen from 1901 to the present.

Appendix A. Alternative regression approaches for simulating third-year survival.

Alternative 1: Correlation function.

We applied a simple auto-correlation function to third year survival, by modeling this value as

$$\ln\left[\frac{s_3(t)}{1-s_3(t)}\right] = \mu + \rho \cdot \ln\left[\frac{s_3(t)}{1-s_3(t)}\right] + \varepsilon_t$$

where μ is the mean transformed survival, ρ is the first-order correlation coefficient and ε_t is a normally distributed error term. We transformed the survival data because the residuals were closer to a normal distribution based on observation of normal probability plots. The model fit for the climate model $R^2 = 0.742$ while the fit for the first-order correlation model was $R^2 = 0.442$. Both these fits were over the time period 1966-2002, which covered the entire period of SAR data. For the autocorrelation model, we estimated three sets of parameters based on different time periods of the SAR data: historical (1964-2002), bad (1977-1997), and recent (1977-2002). When we ran the model with the climate function, we ran climate scenarios using PDO data from the bad and recent time periods just mentioned, but for the historic scenario we used PDO data dating back to 1900.

Alternative 2: Alternate sets of years used in the regression model.

Regression results for 1966-2000:

Residual Standard Error = 0.5044, Multiple R-Square = 0.7404
N = 35, F-statistic = 29.4772 on 3 and 31 df, p-value = 0

	coef	std.err	t.stat	p.value
Intercept	-2.6067	0.0938	-27.7898	0.0000
X1	0.7831	0.2036	3.8456	0.0006
X2	-1.7570	0.2493	-7.0475	0.0000
X3	0.5171	0.1539	3.3604	0.0021

Regression results for 1978-2000:

Residual Standard Error = 0.4414, Multiple R-Square = 0.7251
N = 23, F-statistic = 16.7082 on 3 and 19 df, p-value = 0

	coef	std.err	t.stat	p.value
Intercept	-2.7061	0.1590	-17.0225	0e+00
X1	1.0671	0.2240	4.7644	1e-04

X2	-1.9391	0.3027	-6.4055	0e+00
X3	0.5585	0.1706	3.2738	4e-03

Regression results for 1966-2000 (minus 1985-1991):

Residual Standard Error = 0.5141, Multiple R-Square = 0.7584
 N = 28, F-statistic = 25.118 on 3 and 24 df, p-value = 0

	coef	std.err	t.stat	p.value
Intercept	-2.5414	0.1030	-24.6702	0.0000
X1	0.7277	0.2420	3.0073	0.0061
X2	-1.6559	0.2851	-5.8084	0.0000
X3	0.4499	0.1704	2.6396	0.0144

Regression results for 1966-2000 (with $S_t = D*0.98$):

Residual Standard Error = 0.5031, Multiple R-Square = 0.7396
 N = 35, F-statistic = 29.3486 on 3 and 31 df, p-value = 0

	coef	std.err	t.stat	p.value
Intercept	-2.5975	0.0936	-27.7618	0.0000
X1	0.7827	0.2031	3.8530	0.0005
X2	-1.7496	0.2487	-7.0357	0.0000
X3	0.5127	0.1535	3.3404	0.0022

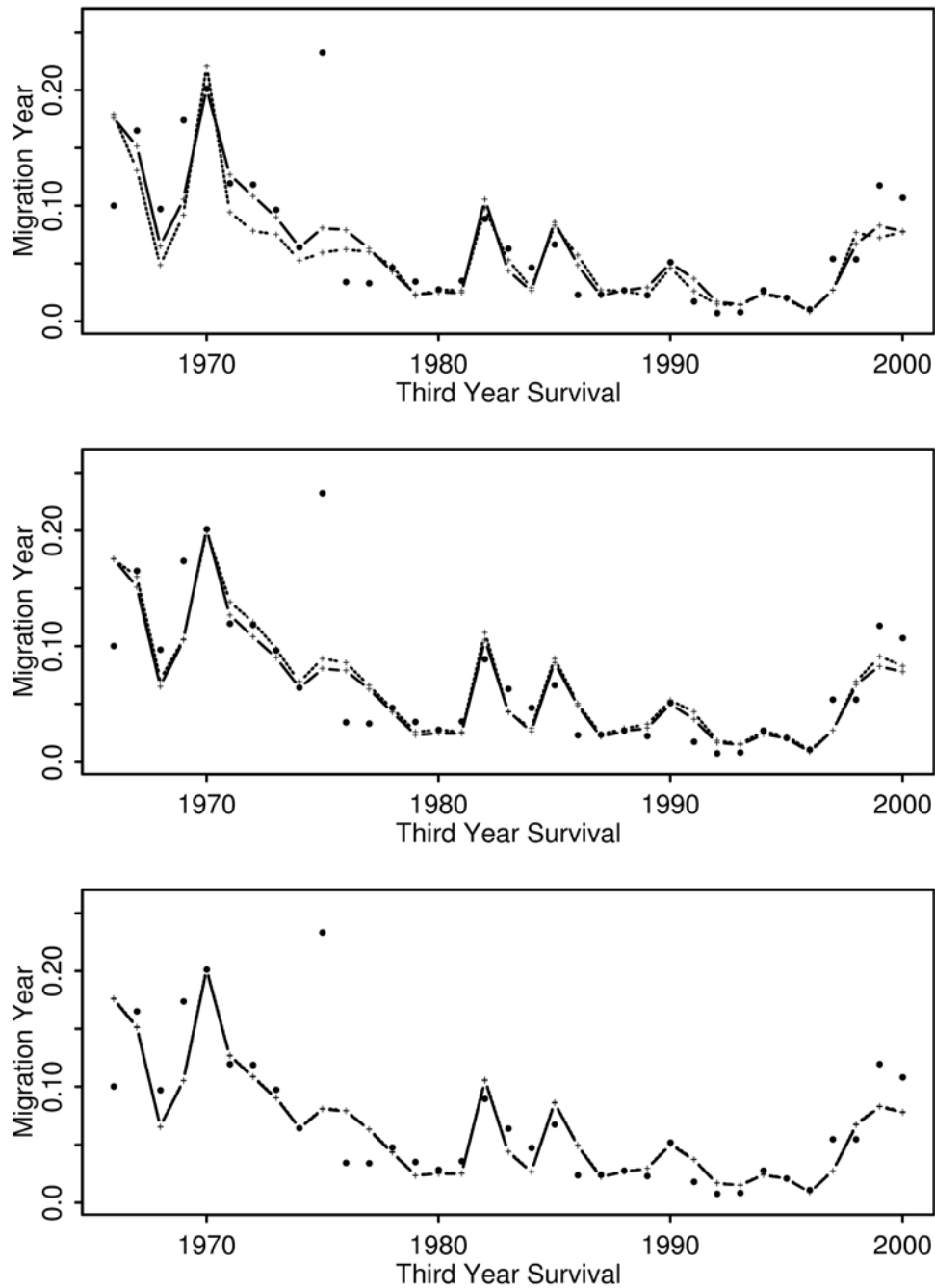


Figure 1. Comparisons of various fits to the data. In all three plots, the solid line is the fit to the full time series (1966-2000). In the top plot, the dashed line is the model prediction using the recent time series, 1978-2000. In the middle plot, the dashed line is the model prediction using the time series with 1985-1991 omitted. In both these cases, the model was fit using the reduced time series, but then applies to the fulltime series. In the bottom plot, the dashed line represents the fit when setting $S_t = 0.98 * D$.

Conclusion: Alternate year scenarios do not provide substantially different fits.

Alternative 3 – alternative climate indices

Comparison of climate indices in fits to S_3

Table 1. Model fits for S_3 versus **upwelling** (45N, 125W) using the latest S_3 (2/13/06) estimates for 1966-2001.

Terms	R^2	AIC
April, October	0.408	23.956
April	0.351	23.963

Table 2. Model fits for S_3 versus monthly **PDO** indices using the latest S_3 (2/13/06) estimates for 1966-2001.

Terms	R^2	AIC
April, May, June	0.745	15.177
April, May	0.653	16.279
May	0.556	17.533

Table 3. Model fits for S_3 versus **sea surface temperature** (45N, 125W) using the latest S_3 (2/13/06) estimates for 1966-2001.

Terms	R^2	AIC
March, November	0.188	30.847
March	0.154	30.131

Conclusions:

PDO fits much better than upwelling or sea surface temperature. Also, PDO fits with just May fit the S_3 estimates substantially more poorly than fits that included April and June (based on AIC and R^2).

Alternative 4 – Combination of PDO and Upwelling Indices

Residual Standard Error = 0.4987, Multiple R-Square = 0.7888
 N = 29, F-statistic = 17.176 on 5 and 23 df, p-value = 0
 AIC = 8.878

	coef	std.err	t.stat	p.value
Intercept	-2.6470	0.1139	-23.2349	0.0000
Upwell Apr	0.0051	0.0051	1.0124	0.3219
Upwell Oct	-0.0067	0.0049	-1.3690	0.1842

PDO Apr	0.5867	0.2462	2.3826	0.0258
PDO May	-1.4754	0.3087	-4.7797	0.0001
PDO Jun	0.4581	0.1663	2.7541	0.0113

Residual Standard Error = 0.4989, Multiple R-Square = 0.7793
 N = 29, F-statistic = 21.1918 on 4 and 24 df, p-value = 0
 AIC = 8.607

	coef	std.err	t.stat	p.value
Intercept	-2.6191	0.1106	-23.6839	0.0000
Upwell Oct	-0.0075	0.0048	-1.5618	0.1314
PDO Apr	0.6608	0.2352	2.8095	0.0097
PDO May	-1.6102	0.2787	-5.7785	0.0000
PDO Jun	0.4765	0.1654	2.8806	0.0082

Residual Standard Error = 0.5131, Multiple R-Square = 0.7569
 N = 29, F-statistic = 25.9489 on 3 and 25 df, p-value = 0
 AIC = 8.687

	coef	std.err	t.stat	p.value
Intercept	-2.5392	0.1008	-25.1800	0.0000
PDO Apr	0.6851	0.2413	2.8387	0.0089
PDO May	-1.6624	0.2845	-5.8431	0.0000
PDO Jun	0.4867	0.1700	2.8627	0.0084

Conclusion: combining upwelling and PDO indices does not provide a substantially better fit than PDO alone.

Alternative 5 (in development): -- combination of May PDO with upwelling and water travel time as predictors.

These are preliminary results. We are currently exploring the use of this option to address concerns that monthly PDO indices are correlated, and are not independent predictors.

2006 1 S3 relation to WTT, Ocean indices 11:02 Monday, May 1,
 Variable D, Sar time series minus 1986-91
 Snake River spring/summer Chinook TRT Gap HS CP

The REG Procedure
 Model: MODEL1
 Dependent Variable: M_LN_s3_VD

Adjusted R-Square Selection Method

Number of Observations Read	31
Number of Observations Used	29
Number of Observations with Missing Values	2

Number in Adjusted

Model	R-Square	R-Square	AIC	BIC	Variables in Model
3	0.6834	0.7173	-32.6634	-29.2475	WTT__days_ MayPDO AprUP45n
4	0.6764	0.7226	-31.2145	-27.2179	WTT__days_ MayPDO AprUP45n OctUP
2	0.6216	0.6486	-28.3516	-26.6337	WTT__days_ AprUP45n
3	0.6125	0.6541	-26.8071	-25.0587	WTT__days_ AprUP45n OctUP45n
3	0.6022	0.6448	-26.0411	-24.4992	WTT__days_ MayPDO OctUP45n
2	0.5981	0.6268	-26.6099	-25.2420	WTT__days_ MayPDO
3	0.4613	0.5190	-17.2470	-17.8571	MayPDO AprUP45n OctUP45n
2	0.4587	0.4973	-17.9715	-18.1932	MayPDO AprUP45n
2	0.4564	0.4952	-17.8489	-18.0912	MayPDO OctUP45n
1	0.4444	0.4642	-18.1202	-17.8986	MayPDO
2	0.3117	0.3608	-11.0039	-12.3103	WTT__days_ OctUP45n
1	0.2851	0.3106	-10.8120	-11.3953	WTT__days_
2	0.2693	0.3215	-9.2704	-10.8191	AprUP45n OctUP45n
1	0.2643	0.2906	-9.9790	-10.6461	AprUP45n
1	0.0588	0.0924	-2.8365	-4.1550	OctUP45n

S3 relation to WTT, Ocean indices 11:02 Monday, May 1, 2006 2
 Variable D, Sar time series minus 1986-91
 Snake River spring/summer Chinook TRT Gap HS CP

The REG Procedure

Model: MODEL1

Dependent Variable: M__LN_s3__VD M(-LN(s3))VD

Number of Observations Read	31
Number of Observations Used	29
Number of Observations with Missing Values	2

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	18.10714	6.03571	21.15	<.0001
Error	25	7.13570	0.28543		
Corrected Total	28	25.24285			

Root MSE	0.53425	R-Square	0.7173
Dependent Mean	2.88254	Adj R-Sq	0.6834
Coeff Var	18.53417		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > t	Std'zed Estimate
Intercept	Intercept	1	1.64366	0.27702	5.93	<.0001	0
WTT__days_	WTT (days)	1	0.07220	0.01637	4.41	0.0002	0.50191
MayPDO	MayPDO	1	0.27832	0.11289	2.47	0.0209	0.34113
AprUP45n	AprUP45n	1	-0.0149	0.00529	-2.83	0.0091	-0.38059

Parameter Estimates

Variable	Label	DF	95% Confidence Limits	
Intercept	Intercept	1	1.07312	2.21420
WTT__days_	WTT (days)	1	0.03848	0.10591
MayPDO	MayPDO	1	0.04583	0.51082
AprUP45n	AprUP45n	1	-0.02588	-0.00407

Appendix B. Parameters relevant to survival through the hydropower system used in estimating s_3 .

Outmigration year	Inriver Survival	% Transported	Transport Survival	D	System Survival
1966	0.46	0			0.46
1967	0.47	0			0.47
1968	0.45	0			0.45
1969	0.34	0			0.34
1970	0.17	0			0.17
1971	0.2	0.03	0.98	0.553	0.21
1972	0.09	0.07	0.98	0.553	0.12
1973	0.03	0.07	0.98	0.553	0.07
1974	0.28	0	0.98	0.553	0.28
1975	0.19	0.1	0.98	0.553	0.23
1976	0.1	0.14	0.98	0.553	0.16
1977	0.01	0.56	0.98	0.553	0.31
1978	0.23	0.48	0.98	0.553	0.38
1979	0.19	0.48	0.98	0.553	0.36
1980	0.15	0.55	0.98	0.553	0.37
1981	0.19	0.44	0.98	0.553	0.34
1982	0.19	0.26	0.98	0.553	0.28
1983	0.21	0.25	0.98	0.553	0.29
1984	0.23	0.43	0.98	0.553	0.36
1985	0.25	0.58	0.98	0.553	0.42
1986	0.27	0.51	0.98	0.553	0.41
1987	0.29	0.62	0.98	0.553	0.45
1988	0.31	0.62	0.98	0.553	0.45
1989	0.33	0.57	0.98	0.553	0.45
1990	0.35	0.62	0.98	0.553	0.47
1991	0.37	0.67	0.98	0.553	0.49

Outmigration year	Inriver Survival	% Transported	Transport Survival	D	System Survival
1992	0.39	0.58	0.98	0.553	0.48
1993	0.34	0.885	0.98	0.553	0.52
1994	0.31	0.877	0.98	0.553	0.51
1995	0.51	0.864	0.98	0.553	0.54
1996	0.42	0.71	0.98	0.553	0.51
1997	0.43	0.711	0.98	0.553	0.51
1998	0.51	0.825	0.98	0.553	0.54
1999	0.557	0.859	0.98	0.553	0.54
2000	0.486	0.704	0.98	0.553	0.53
2001	0.279	0.99	0.98	0.553	0.54